DEVELOPMENT OF KSC PROGRAM FOR INVESTIGATING AND GENERATING FIELD FAILURE RATES

VOLUME I: SUMMARY AND OVERVIEW

FINAL REPORT
PRC R-1459

24 MAY 1972

PREPARED FOR
KENNEDY SPACE CENTER

PLANNING RESEARCH CORPORATION

39/8

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Prepared for

Kennedy Space Center
Under Contract No. NAS10-7621

Prepared by

Eloise E. Bean
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FOREWORD

The three volumes of this final report present the results of a study to develop a program for investigating reliability aspects of the Ground Support Equipment of the Kennedy Space Center (KSC). The study is divided into two distinct parts: (1) investigating the reliability of equipment already in use, including field failure rate generation, and (2) investigating the reliability of equipment not yet in design, with particular reference to hardware/software configurations of large real-time systems. The work was performed by Planning Research Corporation under Contract Number NAS10-7621 during the period 24 May 1971 through 24 May 1972 for the Systems Engineering Division, Design Engineering Directorate, John F. Kennedy Space Center. Mr. R. E. Cato, Jr. and Mr. R. Galloway were the technical monitors of various portions of the study, in cooperation with Mr. Otto Fedor.

A study of this type involves the contributions of a number of people. The forward to each volume identifies the PRC personnel responsible for the work reported within that volume. Major authors of each volume are identified on its fly leaf.

Ms. E. E. Bean was the PRC Project Manager for the entire study. E. E. Bean and C. E. Bloomquist were the study team members responsible for Volume I.

ABSTRACT

The three volumes of this report document a variety of activities undertaken in the development of a KSC program for investigating and generating field failure rates for the Ground Support Equipment (GSE) designed by KSC.

The first volume contains a summary and overview of the work accomplished during this study and, as such, summarizes Volumes II and III. Volume II is in the form of a handbook that KSC can use for dissemination of field reliability data generated under this and antecedent contracts. KSC can add data to the handbook using the methodology contained therein for operating on the Unsatisfactory Condition Reports (UCRs) available at KSC. The handbook format has been designed specifically for this purpose and is completely self-contained. It includes summary data, 20 complete Reliability Assessments of Components (RACs), and step-by-step procedures for generating additional data. Issuance of this handbook as a KSC working document requires only the removal of the PRC cover page and forward. Volume III collects the work performed in this study on the problem of how to obtain reliable (i.e., error free) software when software is considered to be a component of a hardware/software ground support system operating in real time. Included in Volume III are recommended procedures to be employed in various phases of software production, from the early design stage to the sustaining engineering phase. A data collection system for the software component of the hardware/software configuration analogous to the UCR system is also recommended together with an indication of the analysis and use of such data to manage costs and schedules associated with software production.

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I. INTRODUCTION

This final report, published in three volumes, documents the work performed for the Kennedy Space Center (KSC) in establishing a KSC program for the continuing investigation of the reliability of Ground Support Equipment designed by KSC. This volume, Volume I, presents a summary and overview of the completed study tasks. Volume II contains a recommended handbook format for displaying ground support equipment (GSE) reliability characteristics, illustrated with data from the Reliability Assessment of Components (RACs) generated during this study. Volume III contains the recommended procedures for attaining reliable (i.e., error-free) software used as a ground system component in hardware/software configurations operating in real time.

A. Background

The work documented in this report is a continuation of a study performed for KSC over the past several years. Earlier effort had addressed the question: Can technician- and engineer-recorded field information be utilized profitably in a reliability assessment of components in field usage? Specifically, can such an assessment be obtained by analyzing solely the data contained in the then defined Unsatisfactory Condition Report (UCR) historical file retained at KSC? The analysis of the UCR system and the development of a methodology to extract pertinent and useful reliability information was reported in Reference 1. The methodology as contained in Reference 1 was applied to four mechanical/electromechanical components[1] of the GSE: Tail Service Masts, Umbilical Swing Arms, regulators and solenoid valves.

The results of Reference 1 were encouraging enough to proceed with the second phase of the study; that is, to determine if the methodology developed could also be applied to electrical and electronic

[1] Throughout the discussions of this report, "component" is defined as a matrix of parts, assemblies, or subassemblies, typically self-contained, that function in a defined manner relative to overall equipment operation. Defined in this manner equipments of widely different complexity may be termed "components," Tail Service Masts and regulators, for example.

components and, if so, to develop a reporting document for the reliability assessment of components (RACs) of KSC GSE that could be used by various KSC personnel. Reference 2 documents the results of that activity.

Reference 2 contains the final version of the developed methodology and RACs for seven GSE components. The recommended method of dissemination of the information of the RACs in Reference 2 was by incorporation into the handbook of the Kennedy Approved Parts List, a documentation system then being developed concurrently with the Phase II study.

The study documented in the three volumes of this report is the third phase in the overall effort even though the reports are not officially titled Phase III. The original study plan for this phase called for three specific tasks. The first was to review the UCR system as it operated in early 1971 (the system underwent radical changes in October 1969) and to determine the impact, if any, on the methodology developed under the earlier system. The second task involved continued methodology application. PRC's effort in this task was two-fold. First, the RACs for 11 critical components as defined by KSC were to be generated by PRC personnel and a format for a potential KSC handbook for displaying the reliability information was to be developed. Second, PRC personnel were to act as consultants in training sessions of KSC personnel to enable a smooth "transfer" of the techniques involved in RAC generation. The third original task was defined as methodology extension incorporating new areas, such as testing and maintenance.

Subsequent to the beginning of the study activities, the third task discussed above was eliminated and replaced with the task concerning reliability of hardware/software configurations used in real-time, ground support systems.

B. Summary of Study Tasks

1. Task 1: Review of UCR System

The major objective of this task was to review the UCR system as it currently operates with particular reference to the impact, if any, on the methodology for RAC production developed prior to the date of the UCR revision (15 October 1969). The review indicated that the methodology is applicable to both the revised system and the system as it existed prior to 15 October 1969. Several recommendations concerning both the UCR form, the UCR coding system, and the overall mechanics of the system are made in Section II as a result of this review.

2. Task 2: Methodology Application

This task had two major objectives. The first was to provide "transference assistance" to KSC personnel in the effort to have KSC personnel assume all RAC production activities. Conditions prevailing at KSC soon after the beginning of this study limited this training activity to KSC supervisory personnel and the writing of a document giving step-by-step procedures (i. e., a training manual) for RAC generation.

The second major objective of this task was to generate RACs for a KSC selected list of components. The 15 RACs generated by PRC personnel are identified in Section III of this volume and are published in Volume II of this report.

3. Reliability of Hardware/Software Configurations Used in Real-Time, Ground Support Applications

The objective of this task was to identify factors that affect the reliability of hardware/software configurations for large, complex, real-time computer systems. Three major areas were addressed: (1) documentation of the collective effort to date in the computer industry that is directed toward improving the reliability or quality of such configurations; (2) identification of factors that affect the combined reliability of such a configuration; and (3) development of criteria and/or guidelines useful to KSC in its effort to develop and operate such a configuration within limited funds and under severe time constraints. The results are documented in Volume III of this report.

Volume III shows that the current state-of-the-art of software reliability is limited to steps that can be taken to "build reliability into" a hardware/software configuration. While it is desirable to measure software reliability or effectiveness as is done in hardware, this ability must await further theoretical effort. However, as Volume III points out, there are measures that can be made of a hardware/software configuration in the development process that will aid in control of the software reliability.

C. Organization of Volume I

Section II of this document contains the review of the present (1972) UCR system with recommendations for its improvement. Section III discusses the RAC generation performed by PRC in this study, addresses topics pertinent to its application by KSC personnel, and briefly describes the recommended format for a KSC handbook on reliability of GSE. Section IV summarizes the work performed in the hardware/software reliability task. Text references follow Section IV. The Bibliography lists all documentation supplied by KSC as source data for this study.

II. REVIEW OF UCR SYSTEM

Earlier phases of the overall effort investigating the reliability of the KSC Ground Support Equipment were based on the UCR system that was in effect until 15 October 1969. Subsequent to that date several changes were made in the system, both in terms of actual data collected and of physical methods used to store and retrieve the UCR information. This section considers the "new" UCR system (i. e., the one in effect after 15 October 1969) by briefly discussing certain aspects of the revised system, by assessing its impact on RAC generation, and finally by providing recommendations for KSC consideration for improvement of the UCR system.

A. The UCR System After 15 October 1969

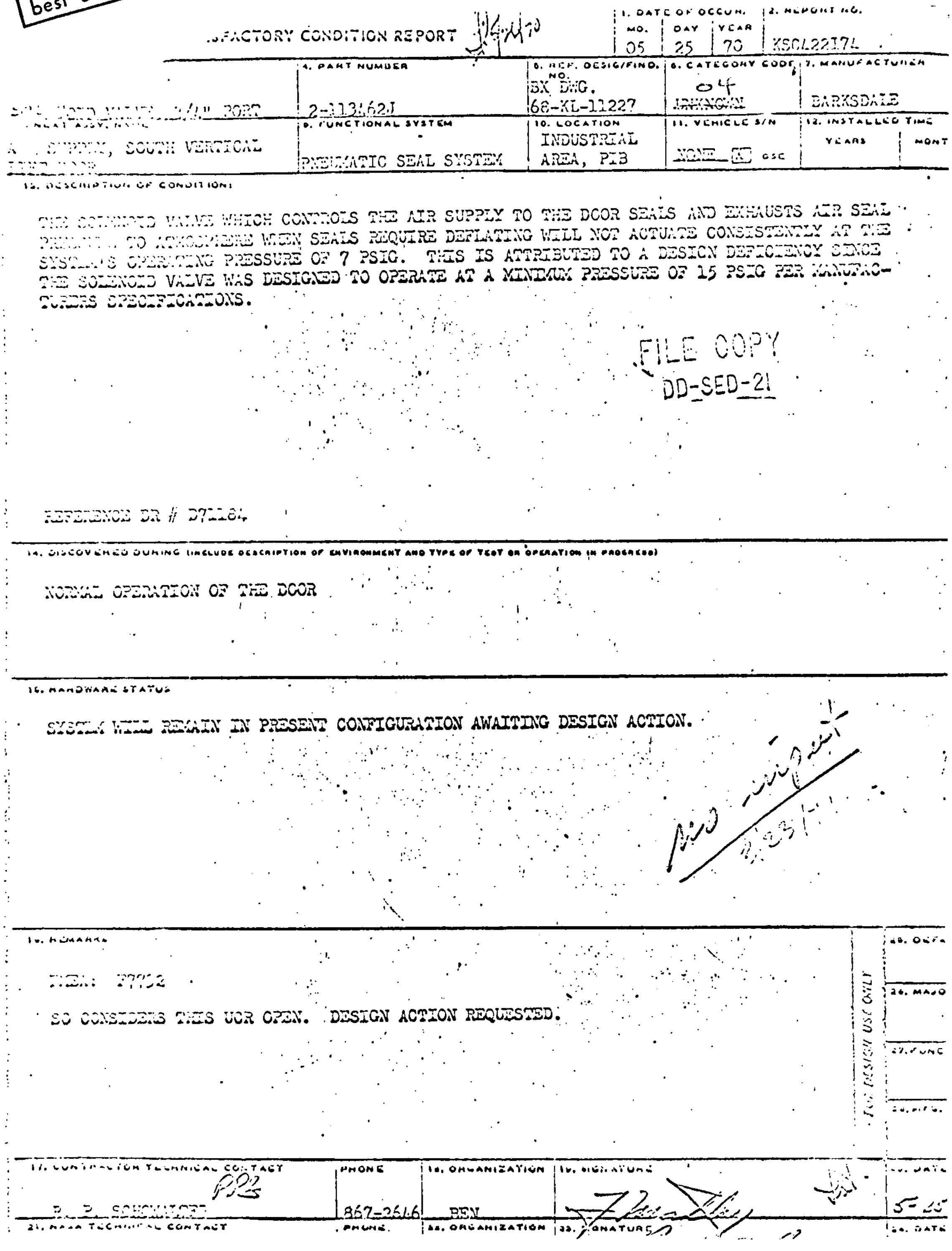
1. General

The UCR system as it existed prior to 15 October 1969 was described and critiqued in Reference 1. Knowledge of the material given in Reference 1 is presupposed in the discussion to follow.

In the summer of 1969 the reporting format for UCRs was revised to produce a somewhat simpler form. For convenience of discussion, the revised form is shown in Exhibit 1.[1] In general, the instructions for its generation did not vary significantly from the instructions previously used. The purpose for the form was retained: to report to Design Engineering (DE) the unsatisfactory condition of any element of the GSE under the cognizance of DE for which action by DE is required.

Even though the expressed purpose did not change before and after 15 October 1969, as a practical matter significant changes did occur. The most obvious, and most dramatic, change is the reduced rate of UCR submittals. Several reasons have been postulated for this reduction:

[1] Exhibit 1 is a reproduction of a UCR submitted on the revised form. The content of the UCR is not pertinent to the discussion. The type of information requested in each block of the form is pertinent.



UNSATISFACTORY CONDITION REPORT 8/4/70

1. DATE OF OCCUR. MO. 05 DAY 25 YEAR 70

2. REPORT NO. KSC422174

3. PART NAME: SOL. CONT. VALVE 3/4" PORT

4. PART NUMBER: 2-113462J

5. REF. DESIG/FIND. NO.: BX DWG. 68-KL-11227

6. CATEGORY CODE: 04 ~~UNKNOWN~~

7. MANUFACTURER: BARKSDALE

8. NEXT ASSY. NAME: AIR SUPPLY, SOUTH VERTICAL LIFT DOOR

9. FUNCTIONAL SYSTEM: PNEUMATIC SEAL SYSTEM

10. LOCATION: INDUSTRIAL AREA, PIB

11. VEHICLE S/N: NONE ☒ GSC

12. INSTALLED TIME: YEARS MONT

13. DESCRIPTION OF CONDITION:

THE SOLENOID VALVE WHICH CONTROLS THE AIR SUPPLY TO THE DOOR SEALS AND EXHAUSTS AIR SEAL PRESSURE TO ATMOSPHERE WHEN SEALS REQUIRE DEFLATING WILL NOT ACTUATE CONSISTENTLY AT THE SYSTEM'S OPERATING PRESSURE OF 7 PSIG. THIS IS ATTRIBUTED TO A DESIGN DEFICIENCY SINCE THE SOLENOID VALVE WAS DESIGNED TO OPERATE AT A MINIMUM PRESSURE OF 15 PSIG PER MANUFACTURERS SPECIFICATIONS.

FILE COPY
DD-SED-21

REFERENCE DR # D71184

14. DISCOVERED DURING (INCLUDE DESCRIPTION OF ENVIRONMENT AND TYPE OF TEST OR OPERATION IN PROGRESS)

NORMAL OPERATION OF THE DOOR

15. HARDWARE STATUS

SYSTEM WILL REMAIN IN PRESENT CONFIGURATION AWAITING DESIGN ACTION.

No impact
8/23/71

16. REMARKS

ITEM: F7702

KSC CONSIDERS THIS UCR OPEN. DESIGN ACTION REQUESTED.

FOR DESIGN USE ONLY

25. OEFA

26. MAJO

27. FUNC

28. MFG.

17. CONTRACTOR TECHNICAL CONTACT: R. P. SCHUMACHER RPS

PHONE: 867-2646

18. ORGANIZATION: BEN

19. SIGNATURE:

20. DATE: 5-25

21. NASA TECHNICAL CONTACT

PHONE

22. ORGANIZATION

23. SIGNATURE

24. DATE

EXHIBIT 1 - REVISED UCR FORM

- Many previous UCRs were submitted that "should not have been" i. e., many purely maintenance actions were being erroneously reported on UCRs rather than on Discrepancy Reports (DR's)
- The current system incorporates a screening process, thus eliminating inappropriate UCRs from the data bank
- The reduction is due to system stability, i. e., reliability growth
- The reduction is due to decreasing launch frequency
- The reduction is due to a combination of the above.

Brief comments on each of the above reasons are in order.

The analysis performed in this study does not support the proposition that different types of problems are being reported in the new system. That is, maintenance type actions are still being reported.

The second postulated reason for the decreased rate of UCR generation--the screening process--is a contributing factor to the decreased rate but only a very small one. Investigation showed that of all UCRs submitted to the data bank since 15 October 1969 only 43 had been rejected (less than 5 percent of the total).

There is no evidence in the analyses performed to confirm or deny that system stability or reliability growth is a contributing factor to the decreased rate of submittal. If a significant increase in system stability had occurred, it seems reasonable to expect to see it reflected in the new data. The data sample from the new system for each RAC is as yet too small, however, to make a statistically valid statement one way or the other. The only observation that can be made is that field failure rates based on the new data are not all lower than those computed on the data base of the old system.

PRC submits that if system stability is indeed a contributing factor, DE should be able to readily observe this phenomenon via other means. For example, a significant decrease in downtime and/or repair activities and a significant reduction in cost of supporting the last few launches should be easily discernible. Complete resolution of this point was beyond the scope of this study.

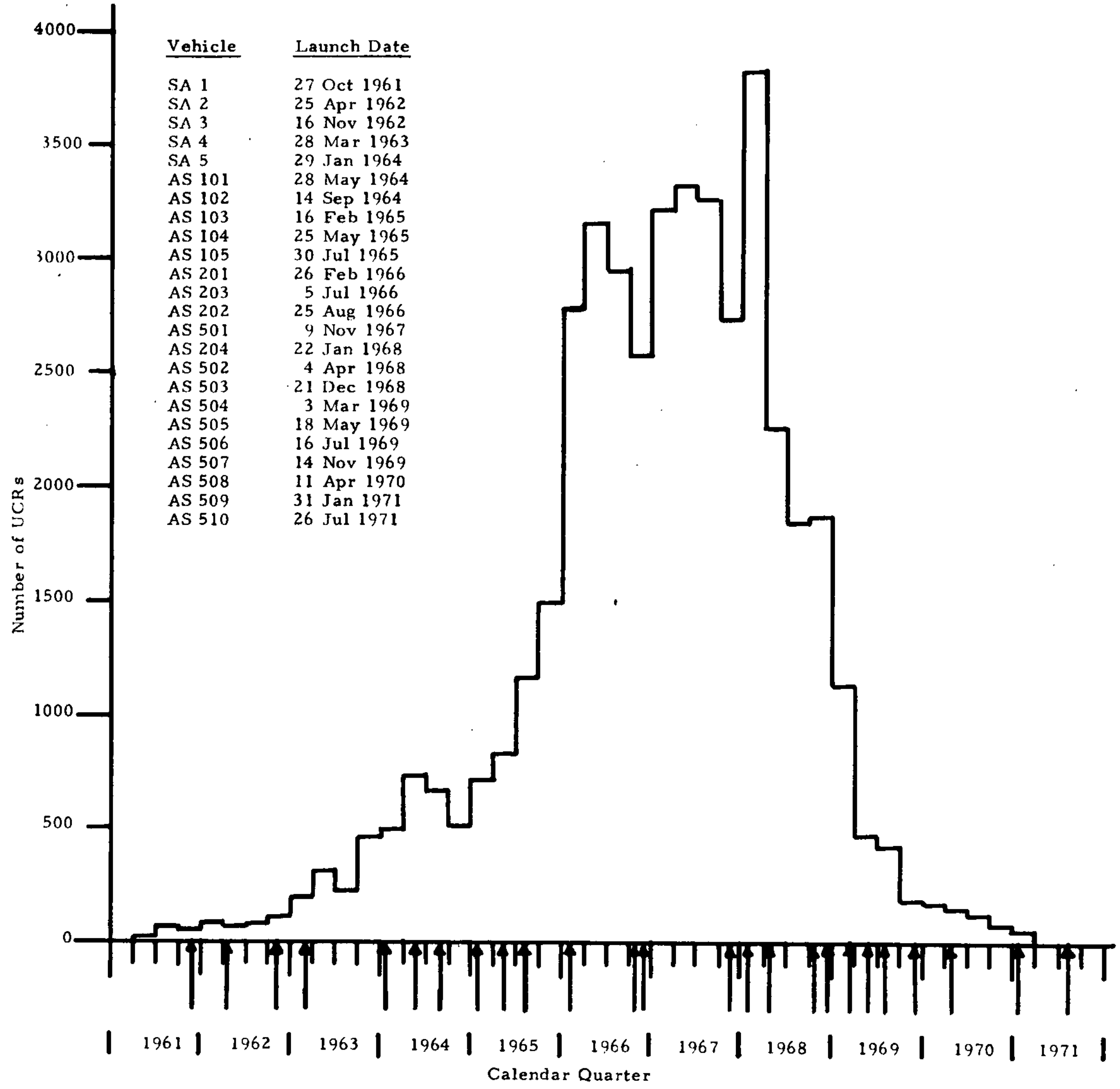
The last point cited above--decreasing launch frequency--does not appear to be valid. Exhibit 2 shows the number of UCRs in both the old and new system by calendar quarter with vehicle launch dates superimposed. Examination of the exhibit clearly indicates that the decline in the rate of UCR generation actually began in the first quarter of 1968 and has continued since that time. Note, however, that from the last quarter of 1968 to the end of 1969 launch frequency was not declining (six launches in 14 months) while UCRs submitted declined steadily from approximately 1,800 per quarter to approximately 200 per quarter.

The actual reason for the rapidly declining rate of UCR submittal is therefore basically unknown to the study team. It most likely involves some combination of the reasons listed above and perhaps some others which are as yet unknown. Emphasis by DE to restrict use of the UCR form to purposes for which it was originally intended may well have caused UCR originators to reduce their output. There also was, in fact, a decrease in launch frequency after 1969, and an increase in reliability for at least some components of the GSE is not unlikely. In view of KSC's intent to continue generating RACs it is to be hoped that DRs are in fact being generated for field problems of interest to this activity.

Other changes evident in the new system are related to entries on the revised form of Exhibit 1 and to UCR coding for file storage. Each of these is discussed in the following paragraphs.

2. Comments on Entries of Revised UCR Form

The revised form shown in Exhibit 1 does not include certain data elements needed for studies of this type. The omitted data elements were included in the old system. In PRC's opinion the most serious omissions are (1) part serial number and (2) replacement part serial number. If the data element required by block 12 on Exhibit 1 (installed time) were always provided, the omission of the serial numbers might not be as significant as it currently is. The developed methodology contains a method of obtaining time information through use of serial



Vehicle	Launch Date
SA 1	27 Oct 1961
SA 2	25 Apr 1962
SA 3	16 Nov 1962
SA 4	28 Mar 1963
SA 5	29 Jan 1964
AS 101	28 May 1964
AS 102	14 Sep 1964
AS 103	16 Feb 1965
AS 104	25 May 1965
AS 105	30 Jul 1965
AS 201	26 Feb 1966
AS 203	5 Jul 1966
AS 202	25 Aug 1966
AS 501	9 Nov 1967
AS 204	22 Jan 1968
AS 502	4 Apr 1968
AS 503	21 Dec 1968
AS 504	3 Mar 1969
AS 505	18 May 1969
AS 506	16 Jul 1969
AS 507	14 Nov 1969
AS 508	11 Apr 1970
AS 509	31 Jan 1971
AS 510	26 Jul 1971

EXHIBIT 2 - NUMBER OF UCRS BY CALENDAR QUARTER, VEHICLE LAUNCH DATES SUPERIMPOSED

numbers, a method which cannot be utilized under the new system. Time is the most often missing item in the old system as well as the new. Of the 963 UCRs of the new system available to this study, only 274 have entries in block 12.

Equally as serious an omission is the next assembly part number and serial number. There are components for which a RAC is desired but for which there is no data retrieval method except by next assembly part number (Tail Service Masts; at Launch Complex 39, for example). For this study analysis, the Tail Service Mast RAC was updated, but only because of the small number of UCRs in the new system (≈1,000) was amenable to hand sorting. Any growth in the UCR historical file would seriously hamper the ability to retrieve such components manually.

In the analyses associated with RAC production it is often helpful to have the number of defects on which the UCR is being written. In the revised form of Exhibit 1 this information may or may not be recorded in the narrative portions. A block for this data element should be restored to the top portion of the UCR form.

Previously generated RACs were able to display repair information for many of the components. The revised form eliminates these data elements. If KSC desires to continue repair analysis, resort to DRs may be required to obtain the basic information.

A very helpful data entry omitted in the revised form is the "related UCR number(s)." The space allowed for it in the old UCR system was inadequate; UCR originators quite often recorded this pertinent information in the narrative sections.

Two entries on Exhibit 1 are of marginal value to purposes of this study: category code and manufacturer. Neither is used directly in the component analyses.

3. Comments on UCR Coding Used in Revised Systems

One of the continuing difficulties in retrieving UCRs to form a data base for analysis has been the inconsistency in key punching part numbers. The revised system retains this problem. The retrieval program should have the capability of sorting and retrieving by part number, a procedure that is hampered by the varying ways part numbers are recorded.

The revised codes for "functional systems" are an improvement. There is now a better agreement between the UCR codes and the codes used by DE and the operational personnel for functional systems.

The revised codes for "defect" while indicating some improvement from previous codes, still retain a basic problem. At least four categories of information are included in the listed codes. These categories are: (1) failure mode codes, such as F06, failed closed; (2) residual condition codes, such as B07, broken; (3) failure cause codes, such as C09, contamination, pollution; and (4) failure symptoms, such as I 11, improper output. It is, of course, theoretically possible that all four codes could be assigned in a particular instance; current practice is to assign only one code. For RAC purposes, both failure mode and cause are important. Currently, the analyst must deduce both mode and cause from the narrative on the UCR and its associated ICAR. From the long range position, coding both the failure mode and cause directly on the UCR would facilitate eventual automation of some of the counting associated with the RAC tabular displays, a process now requiring hand sorting and counting.

In RAC preparation one of the most important codes in the UCR system is the major item. Its importance is simply that UCR retrieval is easy using this code, thus making each item on the major item list a potential candidate for a RAC. Assembling a data base by retrieving UCRs on the basis of part numbers, while more desirable than using the major item approach, remains ineffective until a uniform method of recording by part numbers is devised and/or until a configuration system is imposed. Elimination of next assembly number has effectively closed another approach for assemblying a data base for RAC generation. These last two facts make it mandatory to rely on the major item list as the primary method for retrieving UCRs for analysis. Revisions to this code list should consider this point and items might be included on the list which would benefit from RAC generation activities.

4. Comments on Proposed Revised UCR Form

Exhibit 3 is a reproduction of a proposed revised UCR form that PRC was requested to review as a part of this study. It differs from Exhibit 1 in the following ways: (1) three new data elements are incorporated and (2) one data element formerly allotted space for a narrative has been allotted a smaller block. The new elements are:

o	Manufacturer's Part Number:	Block 5
o	Serial or Model Number:	Block 6
o	Next Assembly Part Number:	Block 9

The data element, "discovered during," has been relocated from the narrative section to the top portion.

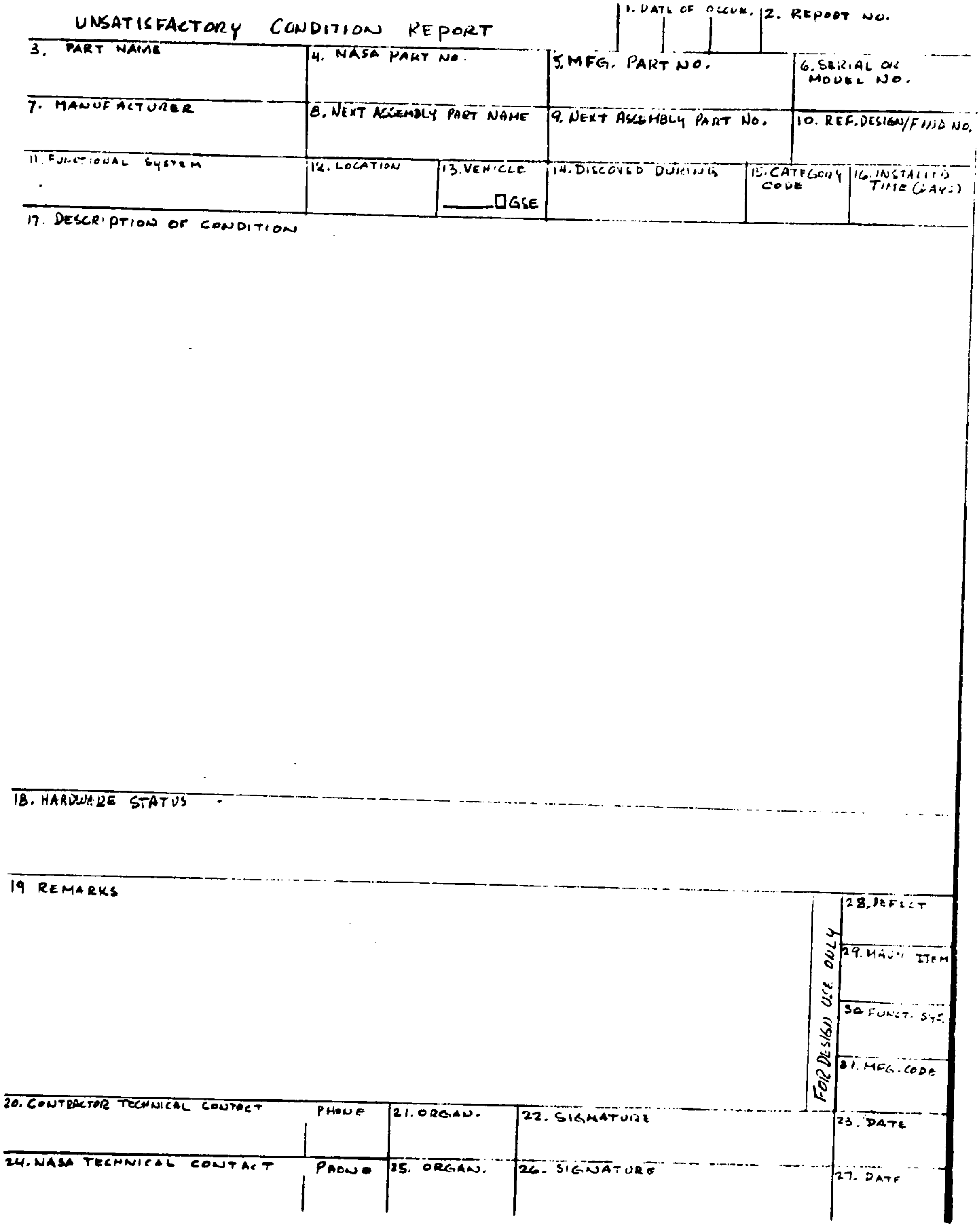
The addition of Serial Number and Next Assembly Part Number is strongly endorsed by PRC for reasons discussed earlier. The addition of manufacturer part number has no implications for RAC generation.

Although PRC is in concurrence with the revisions as shown in Exhibit 3, there are several recommendations discussed in the preceding paragraphs that should be considered for incorporation before a revised form is submitted for review. Subsection II. C below collects all such recommendations.

B. Impact of UCR System Revision as of 15 October 1969 on RAC Generation Methodology

The revisions of the UCR system in October 1969 have no effect per se on the methodology developed for analyzing UCRs to obtain reliability information for components. There are minor recommendations that will be made in the following subsection to improve certain aspects of the process, but none arise solely due to incompatibility between UCR system and methodology.

The reduction in UCRs experienced under the revised system is not believed to be the direct result of the revised system itself as discussed in the preceding subsection. However, even though the observed reduction does not impact the methodology directly, there is an effect that must be acknowledged.



UNSATISFACTORY CONDITION REPORT

		1. DATE OF OCCUR.	2. REPORT NO.
3. PART NAME	4. NASA PART NO.	5. MFG. PART NO.	6. SERIAL OR MODEL NO.
7. MANUFACTURER	8. NEXT ASSEMBLY PART NAME	9. NEXT ASSEMBLY PART NO.	10. REF. DESIGN/FIND NO.

11. FUNCTIONAL SYSTEM	12. LOCATION	13. VEHICLE _____ □ GSE	14. DISCOVED DURING	15. CATEGORY CODE	16. INSTALLED TIME (DAYS)

17. DESCRIPTION OF CONDITION

18. HARDWARE STATUS

19 REMARKS

FOR DESIGN USE ONLY

28. DEFECT
29. MAJOR ITEM
30 FUNCT. SYS.
31. MFG. CODE

20. CONTRACTOR TECHNICAL CONTACT	PHONE	21. ORGAN.	22. SIGNATURE	23. DATE
24. NASA TECHNICAL CONTACT	PHONE	25. ORGAN.	26. SIGNATURE	27. DATE

EXHIBIT 3 - PROPOSED UCR REVISION

While it is true that the UCR system prior to 15 October 1969 may not have been responsive to certain DE needs, the UCR originators were submitting data sheets on a large variety of problems that were amenable to field failure rate analyses. In such analyses all field problems or anomalies that cause a work stoppage and/or expenditure of monies are of interest. The thrust of field failure rate analysis is to isolate those factors influencing the magnitude of the failure rates, take steps to remove the influencing factors and thereby reduce the observed failure rate. For reasons discussed in Reference 1 it was decided to base this work on the UCR system alone (i. e., excluding DRs). The size of the data sample under the earlier (prior to 15 October 1969) UCR system was such that it could be considered a representative sample of field problems occurring at KSC. If, in fact, the reduction of UCRs under the revised system is due to fewer UCRs being generated as a result of the insistence that many maintenance-type problems be reported on DRs, then the analyses associated with the new system can not be said to be based on a representative sample of field failures but rather a specific subset of such problems. In any event, the decreased rate of UCRs is a serious hindrance to the generation of field failure rates. As the decreased rate of UCR submittal is expected to continue for the foreseeable future, DE should seriously consider a consolidated system combining DRs and UCRs under one reporting system. This would enable both maintenance and design engineering information to be collected on a single form, and thereby giving much better visibility into all KSC GSE problems. The basic methodology for generating field failure rates should be directly applicable to DRs as well as to UCRs.

C. Recommendations

This section summarizes the various recommendations PRC submits for KSC consideration involving various aspects of the UCR system.

1. UCR Form

Using Exhibit 3 as a starting point, PRC makes the following recommendations.

a. Interchange Blocks 5 and 6

By placing "serial number" adjacent to "NASA Part Number," the originator is more likely to give the NASA serial number than the manufacturer's model number. For purposes of this study the NASA serial number is preferred over the manufacturer's model number.

b. Operating Time

In order not to lose data that may be available, it is recommended that Block 16 be arranged in two parts, requesting either installed time or operating time.

c. Number of Defects

Add a block prior to the narrative section for the recording of the number of defects being reported on the UCR. This block is recommended for clarity; the number of defects is sometimes clear in the narrative and sometimes not.

d. Number of Replacement Parts

On UCRs reporting a problem on a relatively complex equipment, it is of interest to know how many parts were replaced within it. Sometimes this information is given in the narrative, sometimes not. By including this data element in a block at the top, at least minimal information about the unsatisfactory equipment is obtained.

e. Replacement Part Serial Number

A block for the serial number of the replacement part of the equipment being reported on the UCR is desired. It is used as part of the alternate method of computing time for failure rate calculations.

f. Next Assembly Serial Number

This data item is quite helpful in the analysis of those components for which the data base must be retrieved via the "next assembly part number." A block for this information should be added prior to the narrative section.

g. Related UCR Numbers

This information is often available to the UCR originator at the time the form is being filled out. These related numbers, recorded on the form, are of great benefit to the analyst preparing RACs at a later date. It is recommended that a line stating "give related UCR numbers; if known" be added in parentheses immediately following the title of Block 19, Remarks.

h. Failure Cause and Mode

It is recommended that Block 28 be divided into two parts (or add a second block altogether), one part for failure mode code and the other for failure cause code. For this recommendation to be effective, a corresponding revision would be required in the code tables.

2. Code Tables

In general, the revisions to the code tables are an improvement over the earlier versions. The following codes, however, should be under continuing surveillance.

a. Functional System Codes

A continuing effort to align the codes of the functional systems in a one-to-one correspondence with the functional systems names used by other organizations at KSC is encouraged.

b. Major Item

Continuing surveillance of the entries on this code table is recommended since these items are the most likely candidates for RACs.

c. Defect Code

It is recommended that this table be revised to show codes at least for failure modes and codes for failure causes. This recommendation is effective only if implemented in conjunction with subsection II. C. 1. h above.

3. UCR Printouts

To obtain a data base of UCRs for RAC generation it is necessary that pertinent UCRs be obtainable in hard copies. These printouts are used extensively by the analyst; the format of the printouts can materially affect the time required for data analysis. The following two recommendations are offered in the interest of ease of analysis of the UCRs as they exist after 15 October 1969: (1) space between lines or groups of lines rather than single spacing and (2) print a UCR and its associated ICAR on one page rather than continuous printing of the data file.

4. Augmenting the UCR Data

It is recommended that the possibility of augmenting the UCR system as it now exists with data from the Discrepancy Reports be examined for RAC generation purposes. A combined UCR-DR historical file system is quite likely to give data samples large enough to continue the development of field failure rates for KSC use.

5. UCR Historical File Prior to 15 October 1969

It is recommended that RACs be generated on the complete historical file of UCRs prior to 15 October 1969 as a first priority. This would accomplish on a one-time basis the analyses of all data available in the historical file and provide all the baseline information possible for the proposed KSC handbook.[1]

6. Screening of UCRs

It is recommended that screening of current UCRs be eliminated so that all UCRs submitted are retained in the historical file. As pointed out earlier, all field problems are legitimate data points for field failure analyses. If for other DE purposes screening is felt to be necessary, consideration should still be given to the retaining of all UCRs submitted for purposes of RAC generation.

[1] See Volume II, Section III.

III. GENERATION OF RACS

The second task of this study phase was directed toward RAC generation based on the UCR historical files. Four subtasks were addressed: (1) generation of RACs by PRC personnel; (2) transference of the capability to produce RACs from PRC personnel to KSC personnel by organized training sessions conducted by PRC; (3) minimal supervision of KSC generated RACs and incorporation of these RACs together with the RACs produced by PRC personnel into a common display system; and (4) development of a recommended format for the display of the reliability information derived by the methodology. This section briefly discusses each of these subtasks.

A. RAC Generation by PRC Personnel

A list of 11 KSC ground support equipment components selected by KSC was supplied to this study. A RAC was requested for each component to be produced in rank order. RACs for the first six were required; RACs for as many of the remaining five components as could be produced within the study constraints were desired. Modification to the study statement of work subsequent to the beginning of this study phase enabled completion of all RACs requested by KSC for which there was sufficient UCR data.

The original list of selected components was:

1. Water System (Water Quench and Industrial Firex Water)
2. OTV (including RF Instrumentation)
3. Valves, Solenoid
4. Holddown Arms (LC-34)
5. DC Batteries
6. Circuit Breakers
7. Relays, family
8. Compressors
9. Connectors
10. Pumps
11. Tail Service Masts (LC-34)

The following were components subsequently added to amplify the second component listed above.

12.	RF Carrier Modulator	MSC-39-W
13.	Pilot Carrier Generator	GSC-39-W
14.	RF Combining Network	GSC-39-W
15.	Cable Equalizer	ESC-39-W
16.	RF Line Repeater Amplifier	ASC-39-W
17.	RF Line Splitter	SSC-39-W
18.	RF Carrier Demodulator	DSC-39-W

Tail Service Masts (LC-34) (number 11 above) were dropped from the list due to inability to identify the desired equipment and therefore in retrieving the appropriate UCRs. Components numbered 14, 15, and 17 in the above list contained no UCRs in the historical file and number 13 had only two UCRs; therefore, no RAC could be produced for these four components.

In addition to the above, a RAC generated in earlier phases of the study-effort was updated: Tail Service Masts, Launch Complex 39. The intent of the update was to explore the effect of the revised UCR system on the methodology for RAC generation that had been developed in the earlier phases. The results of this review for effect were given in Section II of this volume.

Exhibit 4 lists the RACs produced by PRC during all phases of this study. The first 15 were either generated for the first time or updated (by KSC direction) during this study phase. The last five, produced in an earlier phase, are included in the exhibit since they form a part of the recommended handbook, an activity of this phase of the study. The exhibit also shows the number of UCRs used to form the data base for the reliability analysis for each component. The currency date is the date that the UCR historical file was entered to retrieve UCRs. The 20 individual RACs for the components listed in the exhibit are a part of Volume II of this report.

EXHIBIT 4 - COMPLETED RACS BY COMPONENT NAME, SIZE OF ASSOCIATED DATA BASE, AND CURRENCY DATE

Component	Number of UCRs in Data Base			RAC
	Old	New	Total	Currency Date
Water System	303	32	335	13 May 1971
Television System (OTV)	3,348	2	3,350	26 April 1971
RF Instrumentation	39	0	39	26 April 1971
RF Carrier Demodulator	167	0	167	26 April 1971
RF Carrier Modulator	206	0	206	26 April 1971
RF Line Repeater Amplifier	24	0	24	26 April 1971
Solenoid Valves	305	28	333	13 May 1971
Holddown Arms	25	9	34	13 May 1971
Batteries	25	2	27	26 April 1971
Circuit Breakers	166	10	176	26 April 1971
Relays	260	34	294	26 April 1971
Compressors	74	2	76	13 May 1971
Connectors	164	6	170	26 April 1971
Pump Assemblies	92	11	103	13 May 1971
Tail Service Masts (LC-39)	153	13	166	13 May 1971
Cable Assemblies	830	15(1)	830	16 June 1969
Capacitors	738	1	738	16 June 1969
Amplifiers	2,134	117	2,134	15 Sept. 1969
Pressure Switches	120	11	120	16 June 1969
Regulators	193	61	193	10 April 1968

[1] Numbers in dotted box are the number of UCRs for the related components in the file after 15 October 1969. The RACs for these components do not include these UCRs as they were generated in previous study phases.

B. Transference of RAC Generation to KSC Personnel

The ultimate utility of the reliability assessment of components is to aid design and reliability engineers at KSC in their on-going surveillance of the GSC components. As such, the reduction of the UCR data should be an on-going task of KSC personnel, generating new RACs or updating old ones on a priority basis dictated by the schedules of KSC. It has been KSC's intent from the beginning of these studies to develop a methodology for analysis that could become a part of the day-to-day KSC activities. This subtask was designed to provide training sessions for KSC personnel, conducted by PRC personnel, whereby all expertise gained by producing the RACs listed in Exhibit 4 could be easily and effectively transmitted.

Conditions internal to KSC were such that, shortly after contract award, it was necessary to curtail the transference activities to the preparation of a document giving step-by-step procedures for producing a RAC and to the conducting of two training sessions for KSC personnel that would be the supervising personnel for any KSC activity in RAC preparation. The training document is included as a part of Volume II of this report.

C. Supervision of RAC Generation by KSC Personnel

Due to the curtailment of KSC activities for production of RACs imposed after the study began, no RACs have been produced by KSC personnel to date. When this activity is renewed, such RACs may be added to those produced in this study in accordance with the instructions contained in Volume II of this report.

D. Recommended Handbook for Displaying KSC Reliability Information

An important subtask associated with the RACs is to determine and recommend a method of displaying the reliability information that encourages the use of such data. This subsection discusses the recommended format. Volume II of this report is the recommended format illustrated with all available data.

Each RAC is a self-contained report, giving the estimated field failure rate (FFR) and associated confidence limits for the component, an analysis of the factors that contributed to the magnitude of the FFRs, an analysis of failure modes observed, an analysis of failure causes, and where possible, an analysis of repair time statistics associated with the component's use at KSC. These component reports give detailed information on the field experience of the component at KSC and should be consulted by engineers with an interest in details of the data base and analysis results of a given component.

The recommended handbook format currently includes the RACs as an integral part of the handbook. As subsequent RACs are completed, the mere volume of paper involved would suggest that RACs should eventually be compiled in separate volumes.

1. Summarized Baseline UCR Data

There are expected to be users of the reliability information that are not, however, interested in detailed information. For this reason, the recommended handbook format contains sections of summarized data. One such section is called "Baseline UCR Data" and summarizes all those data elements derived from the UCR system prior to 15 October 1969. It is called "baseline" data only because it is more numerous than the data elements based on the UCR system subsequent to 15 October 1969. The Baseline UCR data summaries are tabulations of field failure rates and failure classifications recommended for use. These tabulations are in three major groupings: piece parts, subsystems, and systems; the distinction between the levels of these groupings is not strict. Piece parts are generally small, relatively high population items found in many if not all functional systems. A subsystem, as used in the handbook, is generally a collection of piece parts that is still an integrally functioning unit. A system is generally a collection of subsystems and is often not well defined in terms of constituent hardware.

Included in the tabulations is a confidence factor for each recommended FFR. The confidence factor in each case is the number of failure observations on which the FFR is based. This approach to confidence factors has two advantages. First, a single number can be used which is directly indicative of statistical confidence; that is, the higher the number of failures the more accurate the indicated FFR. Second, this number together with the FFR can be used to enter an exhibit (included in Volume II) which provides the upper and lower 90-percent confidence limits on the FFR.

Summarized tabulations for failure causes and failure modes are also reported in the section of Baseline UCR data by the three hardware levels identified above. A final tabulation summarizes all available repair time statistics associated with a component in the data base.

2. Additional UCR Data

Another section of the recommended format very largely parallels the Baseline UCR data section just discussed but is devoted entirely to data collected from the UCR system after 15 October 1969. As was pointed out in Section II, the FFRs from the old and new systems differ considerably in some cases and the new system generally contains relatively few UCRs. Therefore, the FFRs, etc., calculated from the old system are taken as the baseline and those derived from the new system are presented for whatever influence they might have, in the eyes of the individual user, on the baseline figures. Furthermore, the new figures may be updated as required and should, eventually, supplant the baseline figures entirely. No repair data are available under the new system nor are any data at all available for some items.

3. Supplementary Data

It is quite possible that KSC will desire to issue supplementary data for use until all RACs have been completed. In an actually issued handbook this section would contain failure rate data for KSC GSE derived from sources other than the UCRs and the RAC methodology. In Volume II of this report a section has been reserved for this contingency. Contained in that section are recommendations for the generation and reporting of such data.

4. Methodology for the Reliability Assessment of Components

It is recommended that this section of the handbook contain a reproduction of the previously submitted PRC/SSC report D-1810, Reliability Assessment of Components, 30 July 1971, developed for the transference subtask above. This has been done in Volume II by making only the very minor modifications required to make the document a section of a larger report rather than a report itself.

IV. DESIGN CONSIDERATIONS FOR ATTAINING RELIABLE REAL-TIME HARDWARE/SOFTWARE CONFIGURATIONS

This study task addressed the problem of identifying factors that affect the reliability of hardware/software configurations for large complex, real-time computer systems. This task differs from the task reported in Volume II in that it is concerned with ground support equipment not yet in design. Therefore, it is primarily concerned with identification of methods and procedures that can be used to build reliability into a system, in particular hardware/software configurations required in the KSC launch support role. The complete results of this task are reported in Volume III of this report. This section summarizes the results of Volume III.

A. Purpose and Scope of the Task

The purposes of this task are to (1) document the collective effort to date in the computer industry that has been directed toward improving the reliability or quality of hardware/software configurations; (2) identify those factors that affect the combined reliability of such a configuration, and (3) develop criteria and/or guidelines useful to KSC in its effort to develop and operate such a configuration within limited funds and under a severe time constraint.

The scope of the investigation was limited to the assessment of the state-of-the-art in achieving reliable high-quality software for operational, real-time launch processing systems for space vehicles and to the defining of recommendations for further work in those areas appearing to be fruitful and feasible for the accomplishment of the defined purpose.

B. Summary of Volume III Contents

There are three main discussions contained within Volume III. The first addresses aspects of "software reliability." The meaning of that phrase is defined for the purposes of this task as "the probability that no faults will occur that either delay or abort a scheduled launch that can be attributed to the inability of the software components of the hardware/software configuration to perform their intended function." Using this as a working definition, a brief investigation was made into the relationship or transference value, of proven hardware reliability techniques to this concept of "software reliability." As shown in Volume III, there are many analogous concepts, terms, and techniques used in hardware reliability investigations that have implications for software development, implementation, and measurement. It is emphasized in the discussion of this topic that a direct transference of all hardware concepts, terms, and techniques is not possible nor even desirable.

The second major discussion of Volume III is devoted to an explanation of the software production process, including the activities and products associated with each stage of the process. Details are provided concerning the more effective of the techniques in use today in the computer field that have the objective of "building in" software reliability into system configurations.

PRC divided the software production process into the following general phases:

- requirements specification and conceptual analysis
- requirements allocation and detailed design
- coding
- testing
- integration
- maintenance (sustaining engineering)

Each of the phases of this process is discussed in Volume III according to the traditional management trichotomy of planning, implementing and measuring. In particular, some of the questions considered are:

- What means are available for building-in reliability while planning each phase of the process?
- What means are available for use in implementation?
- What techniques are there for measuring the progress of each phase?

- How can the success of the implementation activity be measured?
- How can we ensure reliability at particular points in the process?
- What data can be gathered in the various phases to promote reliability in subsequent phases?
- What reliability problems are encountered at each phase?
- Are the identified reliability problems attributable to decisions made in an earlier phase?
- What techniques and tools have, in the past, contributed to a successful and reliable software system?

The answers to these questions are collected in Section IV of Volume III and provide a set of techniques and tools with which to manage the production of a software system and to build in the needed reliability.

The third major discussion of Volume III addresses the techniques which attempt to assess the reliability of software. An evaluation is given for further investigations that appear to be fruitful in obtaining meaningful software reliability estimates or measures.

Finally, all recommendations are collected into the last section of Volume III and are in the form of criteria and guidelines that are intended to enhance the chance of obtaining a reliable system under severe cost and time constraints.

The appendix of Volume III contains an annotated bibliography of various aspects of the problems considered in this task.

BIBLIOGRAPHY

The following list contains identification of all documentation supplied by KSC for this study. The items are listed in chronological order of receipt by PRC.

1. "Acceptance Checkout Equipment for Spacecraft," Walter E. Parsons, NASA, John F. Kennedy Space Center, 26 January 1971.

2. Data input form for Kennedy Approved Parts List, KSC Form 21-179 (4/71).

3. "Saturn Component Failure Rates and Failure Rate Modifiers," NASA, George C. Marshall Space Flight Center, 15 January 1971.

4. "Retention and Application of Saturn Experiences to Future Programs," NASA, George C. Marshall Space Flight Center, NASA TM X-64574, 8 March 1971.

5. "Quick Glance," code book for user s of nonconformance reports (KSC Form 22-296, 1/70), prepared by FEC R & QE Branch.

6. Skylab System Review Schedule; one-sheet review schedule.

7. Handwritten list of mechanical component problems prepared for R. Hinson, 19 May 1971.

8. "Nonconformance Reporting andCorrective Action System," John F. Kennedy Space Center Management Instruction, KMI 5310, 11A/QA, 8 January 1971.

9. Four pages extracted from Boeing Company Report, Number D5-16739-3, pages 6-12 through 6-15; data sheets for three part numbers within the Tail Service Mast System.

10. Revised UCR ADP Code Tables, dated 27 March 1970 and 2 March 1971.

11. Master List - Old System, UCR Code Tables dated October 1969.

12. "Saturn V Composite Mechanical Schematic," George C. Marshall Space Flight Center, IOM 30531 REV P, 31 August 1970.

13. "Methods and Guidelines to Reduce Launch Cost, Executive Summary," Martin Marietta, 1 September 1969.

14. "Methods and Guidelines to Reduce Launch Cost, Study Summary," Martin Marietta, 1 September 1969.

15. Memorandum transmitting proposed outline for a Handbook on Redundancy and Redundancy Verification, W. R. McMurran, NASA, John F. Kennedy Space Center, 15 April 1971.

16. Phase I Progress Report for Study of Techniques for Automatic Self-Contained Readiness Assessment and Fault Isolation for Ground and On-Board Mechanical Systems, General Electric Company, 70-831-892, 20 July 1970.

17. Phase III Progress Report for Study of Techniques for Automatic Self-Contained Readiness Assessment and Fault Isolation for Ground and On-Board Mechanical Systems, General Electric Company, 70-831-894, 19 October 1970.

18. Final Report for Study of Techniques for Automatic Self-Contained Readiness Assessment and Fault Isolation for Ground and On-Board Mechanical Systems, General Electric Company, 70-831-895, 13 November 1970.

19. Unsatisfactory Condition Report, KSC Form 14-14A, (9/69).

20. Investigation and Corrective Action Report, KSC Form 14-14B (Rev. 12/69).

21. "Space Shuttle Technology Conference," Volume 1 - Operations, Maintenance and Safety, NASA, John F. Kennedy Space Center, TR-1113, 3 May 1971; Volume 2 - Biotechnology, TR-1114, 3 May 1971.

22. LC-34/37 Mechanical Equipment for LC-39, listing dated 11 December 1970.

23. Systems Engineering Study of LC-34/37 Reusable Equipment, internal KSC report, Serial No. SED-3-ER-04, 29 June 1970.

24. Tail Service Mast, System 008, Design Changes, listing, no date.

25. 09, LUT Mechanical Design Changes, Structural, listing, no date.

26. Model numbers for the LC-39 OTV-RF cable transmission system; letter communication, 10 June 1971.

27. Complete UCR printout for old system for following categories:

o Entire file, run dated 26 April 1971.
o Functional system, Industrial Water Supply, run dated 26 April 1971.
o Functional system, RF Instrumentation, run dated 26 April 1971.
o Functional system, Hold Down Arms, run dated 26 April 1971.
o Functional system, Water Quench, run dated 26 April 1971.
o Functional system, Television, run dated 26 April 1971.

28. Selected UCR elements printout for old system for following categories:

    - o By Part Number, 10 UCR elements, run dated 19 March 1971.
    - o By Functional System, 7 UCR elements, run dated 26 April 1971.
    - o By Functional System, 7 UCR elements, run dated 18 May 1971.
    - o By Major Item, 10 UCR elements, run dated 26 April 1971.
    - o By KSC Report Number, 8 UCR elements, run dated 18 May 1971.

29. Complete UCR printout including complete printout of ICAR's for new system for following categories:

    - o Entire file, run dated 13 May 1971.
    - o Functional System, Swing Arms-General, run dated 19 May 1971.
    - o Functional System, Hold Down Arms and Liftoff, run dated 19 May 1971.
    - o Functional System, Tail Service Masts, run dated 19 May 1971.

30. Selected UCR elements printout for new system for following categories:

    - o By major item, 8 UCR elements, run dated 21 April 1971.
    - o By major item, 7 UCR elements, run dated 13 May 1971.
    - o By location, 8 UCR elements, run dated 21 April 1971.
    - o By functional system, 6 UCR elements, run dated 10 May 1971.
    - o By part number, 7 UCR elements, run dated 13 May 1971.
    - o By KSC report number, 6 UCR elements, run dated 13 May 1971.

31. ICARs for old system, complete printout for entire file, run dated 27 March 1971.

32. Thirty-nine UCRs screened from the new UCR program; received September 1972.

33. Draft copy of a KSC specification, received December 1971.

34. One blank copy and one sample copy of a Program Trouble Report, KSC form 23-225 Rev. 9/66; received January 1972.

35. Sample copies of failure rate handbooks; received February 1972.

REFERENCES

1. "KSC Program for Investigating and Generating Field Failure Rates, Phase I," PRC R-1248, 31 December 1968.

2. "KSC Program for Investigating and Generating Field Failure Rates, Phase II," PRC R-1432, 1 May 1970.